CLAIMS

What is claimed is:

1. A system for removing photoresist from a semiconductor substrate comprising:

a processing chamber;

a power source for providing power to a plasma within the processing chamber;

a support for the substrate positioned such that the substrate is exposed to plasma products from the plasma to remove the photoresist;

a gas system configured to maintain a pressure of less than about 500 mTorr in the processing chamber during at least a portion of the time that the substrate is exposed to the plasma products to remove the photoresist.

2. The system of claim 1, wherein the power source delivers a peak ion density of magnitude 10^{10} ions/cm^3 or greater.

3. The system of claim 1, wherein the power source is configured to produce a plasma having an electron temperature in the range of from about 5 to 15 eV.

4. The system of claim 1, further including a second RF power source connected to the support for the substrate.

5. The system of claim 4, wherein the second RF power source is configured to deliver a power in the range of from about 25 to 300 watts to the substrate.

6. The system of claim 4, wherein the power source is configured to produce a current to the support of at least about 0.3 mA/cm^2.

7. The system of claim 1, wherein the temperature of the substrate is less than or equal to about 120°C.

8. The system of claim 7, wherein the temperature of the substrate is less than or equal to about 100°C.

9. The system of claim 7, wherein the temperature of the substrate is less than or equal to about 85°C.

10. The system of claim 1, wherein the power source for providing power to the plasma is selected from the group consisting of a resonant microwave plasma source, a resonant cavity microwave source, a non-resonant microwave plasma source, an ultra high frequency plasma source, a resonant inductive plasma source, a resonant cavity inductive source, and a capacitively coupled plasma source.

11. The system of claim 1, wherein the power source for providing power to the plasma is an electron cyclotron resonance source.

12. The system of claim 1, wherein the power source for providing power to the plasma is a non-resonant microwave plasma source which includes a surface-wave source.

13. The system of claim 1, wherein the power source for providing power to the plasma is an ultra high frequency plasma source which includes an antenna configured to couple electromagnetic energy of frequency greater than about 100 MHz into the plasma.

14. The system of claim 1, wherein the power source for providing power to the plasma is a helicon wave source.

15. The system of claim 1, wherein the power source for providing power to the plasma is a helical resonator.

16. The system of claim 1, wherein the power source for providing power to the plasma is a resonant cavity inductive source configured to operate at a pressure of up to about 300 mTorr.

17. The system of claim 1, wherein the power source for providing power to the plasma is a capacitively coupled plasma source configured to operate at a pressure of up to about 10 Torr.

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18. A method of removing photoresist from a semiconductor substrate, the method comprising:

providing a gas flow to a processing chamber;

providing power from a first source to the gas within the processing chamber to generate a plasma;

providing power from a second source to a substrate support such that the substrate is exposed to plasma products within the processing chamber;

using the plasma products to remove the photoresist; and

maintaining a gas pressure within the processing chamber of less than about 500 mTorr during at least a portion of the time that the substrate is exposed to the plasma products to remove the photoresist.

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19. The method of claim 18, wherein the gas flow includes a principal gas, an inert diluent gas, and an additive gas.

20. The method of claim 19, wherein the principal gas is selected from the group consisting of oxygen, hydrogen, and water vapor.

21. The method of claim 20, wherein the principal gas is oxygen, and the inert diluent gas is selected from the group consisting of a noble gas and nitrogen.

22. The method of claim 20, wherein the principal gas is hydrogen, and the inert diluent gas is selected from the group consisting of helium, argon, and nitrogen.

23. The method of claim 20, wherein the principal gas is water vapor, and the inert diluent gas is selected from the group consisting of helium, argon, and nitrogen.

24. The method of claim 19, wherein the principal gas is oxygen, and the additive gas is selected from the group consisting of water vapor, methyl alcohol, ethyl alcohol, hydrogen, methane, ammonia, methyl amine, ethyl amine, carbon dioxide, formaldehyde, nitrous oxide, nitric oxide, nitrogen dioxide, and oxides of sulfur.

25. The method of claim 19, wherein the principal gas is selected from the group consisting of hydrogen and water vapor, and the additive gas is selected from the group consisting of oxygen, methane, ammonia, water vapor, methyl alcohol, ethyl alcohol, nitrous oxide, nitric oxide, nitrogen dioxide, and oxides of sulfur.

26. The method of claim 18, wherein the gas flow is less than about 3,000 standard cubic centimeters per minute.

27. The method of claim 18, wherein the step of maintaining the gas pressure within the processing chamber at less than about 500 mTorr further comprises maintaining the pressure at less than about 200 mTorr.

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28. The method of claim 18, wherein the step of providing a first source of power to the gas within the processing chamber to generate a plasma further comprises providing a power within the range of about 1,000 to 2,500 watts at a frequency of about 13.56 MHz.

29. The method of claim 18, wherein the step of providing a second source of power to a substrate support further comprises supplying a bias power to the substrate support within the range of about 0.1 to 2.0 watts/cm^2.

30. The method of claim 18, further comprising the step of maintaining the substrate at a temperature of less than about 100°C.

31. The method of claim 24, wherein the additive gas further comprises a halogen.

32. The method of claim 25, wherein the principal gas is hydrogen, and the gas flow further comprises a halogen.

33. The method of claim 25, wherein the principal gas is water vapor, and the gas flow further comprises a halogen.

34. A method of removing photoresist from a semiconductor substrate, wherein the photoresist includes a crosslinked photoresist crust overlying bulk photoresist, the method comprising:

providing a flow of a first gas to a processing chamber;

inductively coupling power to the first gas within the processing chamber to generate a first plasma;

using the first plasma to etch the crosslinked photoresist crust;

providing a flow of a second gas to the processing chamber;

coupling power to the second gas within the processing chamber to generate a second plasma; and

using the second plasma to remove the bulk photoresist.

35. The method of claim 34, wherein:

the first gas flow comprises oxygen at a flow rate in the range of about 40 to 150 standard cubic centimeters per minute, and

the second gas flow comprises oxygen at a flow rate greater than about 1,000 standard cubic centimeters per minute.

36. The method of claim 34, further comprising:

maintaining a pressure in the processing chamber of from about 2 to 10 mTorr during etch of the crosslinked photoresist crust using the first plasma; and

maintaining a pressure in the processing chamber of about 1 Torr during removal of the bulk photoresist using the second plasma.

37. The method of claim 34, wherein:

the power that is inductively coupled to the first gas is in the range of about 1,000 to about 2,500 watts; and

the power that is coupled to the second gas is about 1,000 watts.

38. The method of claim 34, further comprising applying a bias power to a substrate support when the first plasma is etching the crosslinked photoresist crust, wherein the bias power is in the range of about 25 to 150 watts at a frequency of about 13.56 MHz.

39. The method of claim 34, further comprising maintaining the temperature of the substrate at less than or equal to about 100°C during the etch of the crosslinked photoresist crust.

40. The method of claim 34, further comprising maintaining the temperature of the substrate at less than or equal to about 150°C during the removal of the bulk photoresist.

41. The method of claim 34, wherein:

the first gas flow comprises oxygen at a flow rate of less than about 500 standard cubic centimeters per minute;

the second gas flow comprises oxygen at a flow rate within a range of about 1 to about 3 standard liters per minute; and

the temperature of the substrate during exposure to the first plasma is in the range of about 150°C to about 250°C.

42. The method of claim 34, wherein the first gas further comprises an additive gas selected from the group consisting of water vapor, methyl alcohol, ethyl alcohol, hydrogen, methane, ammonia, methyl amine, ethyl amine, carbon dioxide, formaldehyde, nitrous oxide, nitric oxide, nitrogen dioxide, and oxides of sulfur.

43. The method of claim 34, wherein the second gas further comprises an additive gas selected from the group consisting of water vapor, methyl alcohol, ethyl alcohol, hydrogen, methane, ammonia, methyl amine, ethyl amine, carbon dioxide, formaldehyde, nitrous oxide, nitric oxide, nitrogen dioxide, and oxides of sulfur.

44. The method of claim 34, wherein:

the pressure of the first gas in the processing chamber is less than or equal to about 50 mTorr, and

the pressure of the second gas in the processing chamber is about 1 Torr.

45. The method of claim 34, wherein:

the power that is coupled to the first gas to generate the first plasma is at least about 200 watts; and

the power that is coupled to the second gas to generate the second plasma is in the range of about 800 watts to about 1200 watts.

46. The method of claim 34, wherein the temperature of the substrate during the removal of the bulk photoresist is about 250°C.

47. A method of removing photoresist from a semiconductor substrate having vertical, low-k dielectric surfaces and horizontal surfaces, the method comprising:

providing a gas flow to a processing chamber;

providing a first source of power to the gas within the processing chamber to generate a plasma;

accelerating ions from the plasma at directions substantially perpendicular to the plane of the substrate such that the ions impinge on the vertical, low-k dielectric surfaces of the substrate less frequently than on the horizontal surfaces of the substrate.

48. The method of claim 47, wherein the low-k dielectric surfaces are subject to oxidation by oxygen, hydrogen, and hydroxyl radicals from the plasma.

49. The method of claim 48, wherein:

the gas flow comprises oxygen at a pressure within the processing chamber of less than about 1 Torr;

the first source of power is an inductively coupled plasma source which couples power to the gas within the processing chamber in the range of about 200 watts to 5,000 watts;

a second source of power is provided to a substrate support such that the substrate is exposed to plasma products within the processing chamber; and

the bias power to the substrate support ranges from about 0.1 to about 2.0 watts/cm^2.

50. The method of claim 48, wherein:

the gas flow comprises oxygen and is maintained at a pressure within the processing chamber in the range of about 5 mTorr to 2 Torr;

the first source of power is a capacitively coupled plasma source which couples power to the gas within the processing chamber at a level less than about 3.0 watts/cm^2.

51. A method of removing photoresist from a semiconductor substrate having vertical, low-k dielectric surfaces, the method comprising:

providing a gas flow to a processing chamber;

providing a first source of power to the gas within the processing chamber to generate a plasma;

providing a second source of power to a substrate support such that the substrate is exposed to plasma products within the processing chamber;

depositing a protective polymer layer on the vertical, low-k dielectric surfaces of the substrate.

52. The method of claim 51, wherein the gas flow comprises a principal gas selected from the group consisting of oxygen, an oxygen containing gas, hydrogen, a hydrogen containing gas, and water vapor.

53. The method of claim 52, wherein the gas flow further comprises a principal etchant selected from the group consisting of nitrogen oxides, carbon dioxide, ethyl alcohol, methyl alcohol, and sulfur oxides.

54. The method of claim 52, wherein the gas flow further comprises an additive gas selected from the group consisting of alcohol, hydrogen diluted in an inert gas, ammonia, and hydrocarbon.

55. The method of claim 54, wherein the inert gas is selected from the group consisting of helium, argon, and ammonia.

56. The method of claim 54, wherein the hydrocarbon is selected from the group consisting of ethane, methane, butane, ethylene, acetylene, propane, benzene, cyclohexane, and cyclobutane.

57. The method of claim 52, wherein the gas flow further comprises an additive gas comprising a silicon-containing gas and a fluorine-containing gas.

58. The method of claim 57, wherein the silicon-containing gas is selected from the group consisting of silane, disilane, methylated silane, TEOS, and TMCTS.

59. The method of claim 57, wherein the fluorine-containing gas is selected from the group consisting of nitrogen trifluoride, difluoromethane, trifluoromethane, and hexafluoromethane.

60. A method of removing photoresist from a semiconductor substrate in the presence of a silicon and carbon-containing low-k dielectric material, the method comprising:

providing a gas flow to a processing chamber;

providing a first source of power to the gas within the processing chamber to generate a plasma;

providing a second source of power to a substrate support such that the substrate is exposed to plasma products within the processing chamber; and

removing the photoresist.

61. The method of claim 60, wherein the gas flow includes a principal gas, an inert diluent gas, and an additive gas.

62. The method of claim 61, wherein the principal gas is selected from the group consisting of hydrogen, oxygen, and methane.

63. The method of claim 61, wherein the inert diluent gas is selected from the group consisting of a noble gas and nitrogen.

64. The method of claim 61, wherein the additive gas is selected from the group consisting of ammonia, methyl alcohol, water vapor, and a fluorine-containing gas.

65. The method of claim 64, wherein the fluorine containing gas is selected from the group consisting of C_2F_2, CHF_3, and CH_2F_2.

66. The method of claim 60, wherein the gas flow is in the range of about 10 to 1,000 standard cubic centimeters per minute.

67. The method of claim 60, wherein the pressure of the gas within the processing chamber is maintained at less than about 200 mTorr.

68. The method of claim 60, wherein the step of providing a first source of power to the gas within the processing chamber to generate a plasma further includes providing power in the range of about 200 to 2,000 watts.

69. The method of claim 60, wherein the step of providing a second source of power to a substrate support further includes supplying a bias power to the substrate support in the range of about 0.1 to 2.0 watts/cm^2.

70. The method of claim 60, wherein the substrate is maintained at a temperature of less than or equal to about 100°C when the principal gas comprises oxygen and methane, and in the range of about 100°C to 150°C when the principal gas is hydrogen.

71. A method of removing photoresist from a semiconductor substrate in the presence of a non-carbon containing silsesquioxane low-k dielectric material, the method comprising:

providing a gas flow to a processing chamber;

providing a first source of power to the gas within the processing chamber to generate a plasma;

providing a second source of power to a substrate support such that the substrate is exposed to plasma products within the processing chamber; and

removing the photoresist.

72. The method of claim 71, wherein the gas is predominantly oxygen.

73. The method of claim 71, wherein the pressure of the gas within the processing chamber ranges from about 2 to about 200 mTorr.

74. The method of claim 71, wherein the step of providing a first source of power to the gas within the processing chamber to generate a plasma further includes providing a power in the range of about 200 to 2,000 watts.

75. The method of claim 71, wherein the bias power to the substrate support is in the range of about 0.1 to 2.0 watts/cm^2.

76. The method of claim 71, wherein the temperature of the substrate is less than or equal to about 100°C.

77. A method of removing photoresist from a semiconductor substrate in the presence of an organic low-k dielectric material, the method comprising:

providing a gas flow to a processing chamber;

providing a first source of power to the gas within the processing chamber to generate a plasma;

providing a second source of power to a substrate support such that the substrate is exposed to plasma products within the processing chamber; and

removing the photoresist.

78. The method of claim 77, wherein the gas flow comprises a principal gas and an additive gas.

79. The method of claim 78, wherein the principal gas comprises oxygen at less than 50 percent of the total flow.

80. The method of claim 78, wherein the principal gas further comprises a hydrogen containing gas to form a net reducing atmosphere.

81. The method of claim 78, wherein the additive gas is selected from the group consisting of methane, ethane, propane, butane, cyclobutane, cyclohexane, benzene, methanol, ethanol, propanol, carbon dioxide, hydrogen, nitrogen, ammonia, silane, disilane, TEOS, water vapor, formaldehyde, acetaldehyde, and ethylene oxide.

82. The method of claim 77, wherein the gas flow is less than about 1,000 standard cubic centimeters per minute.

83. The method of claim 77, wherein the pressure of the gas within the processing chamber is in the range of about 1 to 200 mTorr.

84. The method of claim 77, wherein the step of providing a first source of power to the gas within the processing chamber to generate a plasma further includes providing a power in the range of about 200 to 2,000 watts.

85. The method of claim 77, wherein the bias power to the substrate support is in the range of about 0.1 to 2.0 watts/cm^2.

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